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ON CRITICAL PILOT TASKS

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Prepared under Contract No. NAS2-5108

Bolt Beranek and Newman Inc.
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for Ames Research Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ABSTRACT

We consider the possibility of formally defining and classifying critical pilot tasks. It seems clear that a task may be of special importance either because there are serious consequences if it is not carried out properly or because it places heavy demands on the pilot in terms of workload, decisions, or control activity. To include both the elements of danger and complexity we propose to define a critical pilot task as one that affords a low probability of recovery from an incorrect pilot decision or control action.

At this point the difficulty of making a general classification of tasks as more or less critical becomes obvious, for the probability of recovery from an error in any given task can be very different for different pilots in the same aircraft or for the same pilot in different aircraft. Individual pilots vary widely in their levels of training, experience, emotional stability, and technical understanding of the response dynamics of the airplane they are controlling. The level of effort that must be expended to reduce the criticality of a certain task will depend on the relative importance of the task in various types of aviation activity: commercial airlines, air taxis, private pleasure flying, aerial applications, and so forth.

We see three basic reasons for a task being critical. A task may have to be performed in a very narrow time window; it may involve an operation near some limit of aircraft performance; it may involve an operation near some limit of pilot capability. Each reason characterizes a class of critical tasks. We identify some of the more important tasks in each of these classes. We also discuss the kinds of steps that may be taken to reduce the

criticality of tasks in each of these three classes. Attempts can be made to minimize the chances that the task will be necessary, extend time limitations, provide additional information to the pilot, relieve the pilot of the task, and so forth.

When the limitations leading to a task being critical are not so evident, the procedures to follow to improve matters are not so easy to determine. In our view the most important of the less-well-defined areas has to do with the pilot's inherent decision-making capabilities. We discuss the four elements of a critical decision in the aeronautical context: detecting that a problem exists, identifying possible causes and their probabilities, evaluating the effects of alternative responses, and choosing one response. To these elements we relate some of the research we have conducted for the Human Performance Branch in the past five years -- research on attention, signal detection, decision making, and reaction time.

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1.0 What is a critical pilot task?

There is a widespread, intuitive feeling among people interested in aviation safety that some pilot tasks and aircraft operations can be classified as "critical." Most pilots have stories to tell about close calls that they have experienced and situations that they consider dangerous. Flight instructors can identify certain maneuvers that their students must be able to execute well in order to fly safely. Many air traffic controllers have hair-raising stories of their own. Aviation-safety experts can detail the circumstances that have led to aircraft accidents.

In light of the rich variety of experience and opinion available, the lack of formal attempts to define and classify critical pilot tasks is surprising. Considerable study has been invested in certain flight situations in which the risk of accident is quite apparent or in which the pilot must make a clearly crucial decision. One such situation is an impending mid-air collision -- great effort has been expended in the search for ways to prevent the close proximity of aircraft, and to provide the pilot with warning devices and decision aids. As another example, there has been much discussion of the go/no-go decision a pilot must make when breaking through a low ceiling on an instrument approach. In this case, there are substantial economic considerations involved in diverting an aircraft to another airport, in addition to safety considerations.

We feel that there is great potential value attached to an incisive definition of a critical pilot task. Such a definition, carefully made, could carry valuable implications. The worth of this approach could be measured by the worth of the concepts that seem to follow from it: the identification of certain classes of critical operations (which may be defined as critical for quite different reasons), and, perhaps, ways of minimizing the features of these operations that led to their being classed as critical.

In the following pages, we propose a definition of a critical task and consider the implications of this definition.

2.0 A proposed definition of a critical pilot task.

A definition of a critical pilot task must include the elements of danger that result if the task is not carried out correctly, and also the demand upon the pilot in terms of work-load, decisions, or control activity. It is apparent that there are some tasks that may entail a high pilot workload, but which may not be dangerous; on the other hand, there are tasks that may require a very simple decision from the pilot, but which carry a very high cost if that decision is not correct. Therefore, instead of predicating the definition solely on either the complexity or the danger of the task, we propose the idea that

> A critical pilot task is one that affords a low probability of recovery from an incorrect pilot decision or control action. The lower the probability of recovery, the more critical is the task.

3.0 Characteristics of a critical task.

The proposed definition of a critical task states that tasks can be rated as more or less critical according to the probability that the pilot will be able to recover from the effects of an incorrect decision or control action. So, in a sense, one cannot speak of "critical" and "non-critical" tasks without identifying (at least implicitly) some point along a "continuum of criticality" that separates the two categories. This identification may prove very difficult because the probability of recovery from an error in performing a certain task may be very different for different pilots in the same aircraft or for the same pilot in different aircraft. This is true because there are several different reasons why the probability of recovery from an error may be low.

3.1 Reasons for a task being critical.

We suggest that there are three basic reasons why the probability of recovery from an error may be low. Each reason characterizes a class of critical tasks.

(a) The nature of the task is such that there is a very narrow time window in which the task must be performed. Therefore, there may not be time for the pilot to second-guess his original decision or control action. This would be the case for an impending mid-air collision situation. To a lesser degree, it would be true when a pilot must decide whether he has adequate runway visibility when breaking through a low ceiling on final approach. In the latter case, the pilot would at least have the option of making an early, conservative decision to go around and try again.

(b) The task involves operation near some critical limit of aircraft performance. Within this class of operations we include not only such well-defined limits as stall speeds, never-exceed velocities, and load factors, but also such task-dependent limits as aircraft courses and altitudes which may bring the aircraft near hazards to navigation. Using this notion, we may speak of a class of critical tasks that involve the operation of an aircraft sufficiently close to its limits that control errors (or even random disturbances) may cause the limits to be exceeded. This class would then include such diverse operations as flying through severe turbulence (where the aircraft load factors may be exceeded), making a final approach in a gusty wind (where airspeed may suddenly drop below stall speed), a noise-abatement departure or short-field takeoff (both of which involve airspeeds near the stall speed), flying through severe icing conditions (where ice buildup on wings may raise the stall speed), and making an instrument approach to a field with hazardous obstructions near the approach path (where a small deviation from the proper path could result in hitting an obstruction).

(c) The task involves an operation near the performance capabilities of the pilot. In general, this class of critical tasks involves a pilot workload (in terms of calculations, decisions, and sensorimotor activities) that is sufficiently high that he may not be able to respond properly if the necessity for a new decision suddenly arises. A high pilot workload of this nature could arise either as a result of the dynamic characteristics of the aircraft -- if, for example, a stability augmenter failed, or if the aircraft is inherently sensitive to side gusts at slow airspeeds -- or as a result of the complexity of the operation being performed, such as flying a complicated traffic pattern on instruments while receiving instructions from the approach controller. In either case, the occurrence of a problem that in other circumstances would prove trivial might result in a pilot overload.

3.2 Identifying a critical task.

As mentioned above, the identification of a critical task is complicated by the fact that the probability of recovery from an incorrect decision or control response depends not only on the nature of the operation being performed, but also on the characteristics of the aircraft and the abilities and experience of the pilot. Different types of aircraft, of course, can have widely different operational limits; they can also vary greatly in their propensity to be "forgiving" of control errors, unusual attitudes, and rough piloting technique. Pilots, too, can have different motor abilities and perceptual acuities. Presumably, however, medical examinations and pilot certification requirements serve to eliminate from the pilot population those individuals who are demonstrably deficient in these respects. Far greater differences between pilots occur in their levels of training, experience, emotional stability, and technical understanding of the response dynamics of the aircraft they are controlling.

In view of these factors, the identification of a well-defined set of critical tasks for all pilots and all aircraft may be impossible. Indeed, such an effort hardly seems worthwhile -- the identification of a situation from which recovery is difficult has little but academic value if this situation very rarely occurs. For example, a stall-spin incident by an airline transport pilot in a commerical airliner clearly meets the criteria of our definition of a critical task, but such incidents do not represent a significant part of the present aviation-safety situation. Stall-spin incidents by student and private pilots in light aircraft, on the other hand, do. We suggest, therefore, that different levels of effort must be expended toward reducing the criticality of various tasks, and that these levels of effort should be different for different classes of aviation activity (commercial airlines, air taxis, private pleasure-flying, aerial applications, etc.).

However, we also suggest that there are some fundamental concepts, common to many of the tasks we have mentioned as critical, that one must be careful not to overlook. One of these concepts, which, we feel, has not received adequate study, is that of the basic decision-making capabilities of the pilot: his abilities to estimate probabilities, to foresee the probable consequences of alternative responses, to judge risks, to estimate accurately his own sensorimotor capabilities, and then to choose the most appropriate response. We discuss the process of decision making in Section 4. Two processes closely related to decision making, namely attention and reaction time, are also discussed briefly in Section 4.

3.3 Making a critical task less critical

In most cases, the very identification of a critical task carries with it some indications of how the task can be made less critical. If a task has been identified as critical because it requires an operation near one of the time, aircraft, or pilot limits discussed in Section 3.1, then the obvious thing to do is to try to extend limits. For example:

(a) If a task requires a decision or control action within a very short time period, then one of three approaches can be employed. First, one can attempt to minimize the chances that the task will become necessary. For the critical task of collision avoidance, this approach would mean scheduling and monitoring aircraft to reduce the probability that any two aircraft would find themselves on a collision course.

For the critical task of judging whether runway visibility is adequate when breaking through a low ceiling on final approach, it might mean eliminating the need for the decision by providing an automatic guidance system that could be employed all the way to touchdown. Second, one can attempt to extend the time period in which the decision can be made and corrected. For the collision-avoidance task, this approach might involve an early-warning system that would allow the pilots to change course well before a collision was imminent. For breakout-on-final, it would suggest either a slower approach speed or some vision-enhancement technique that would give the pilot better runway visibility. Third, one can attempt to provide the pilot with additional information that would increase the probability of his making a correct decision. For collision avoidance, this approach suggests an on-board computer that indicates to the pilot an appropriate climb, dive, or turn to avoid the other aircraft. For breakout-on-final, it suggests the use of automatic runway-detection apparatus.

(b) If a task requires an operation near some limit of aircraft performance, then one can attempt to extend this limit. Obviously, aircraft with lower stall speeds, higher load limits, more reliable instruments, better de-icing equipment, and more forgiving dynamic response will be safer to fly. Equally obviously, approach paths that avoid obstructing terrain and hazards to navigation will be safer to use. Because these facts are so apparent, the operational limitations of existing aircraft have been care lly considered during design and testing. It will be rare that an attempt to extend them will prove fruitful. One exception might be the installation of an angle of attack indicator in aircraft used in crop-dusting applications, where fairly violent maneuvers must be carried out at very low altitude. This would at least allow the pilot to know how close to the critical angle of attack his aircraft is.

(c) If a task involves an operation near the performance capabilities of the pilot, a variety of approaches can be tried. First, one can attempt to relieve the pilot of the critical task, either by minimizing the chances of its occurrence or by providing equipment to execute the task automatically. Second, one can attempt to improve the capabilities of the pilot through intensive training and experience in responding to simulated emergencies. In some cases, this approach can have dramatic results -- the Luftwaffe has recently achieved a significant improvement in the safety record of their F-104s by requiring their pilots to fly them more hours per month. Third, one can attempt to reduce the pilot's workload during the critical task so that he can pay more attention to critical decisions that must be made. Fourth, one can attempt to maximize the probability of a correct decision by providing the pilot with information-processing aids and instruments that will help him decide and respond correctly.

In summary, where the time, aircraft, and pilot limits that result in a critical task are apparent, then the lines along which to attack the problem are also apparent. In the paragraphs above, several of these definable limits have been discussed. Where these limits are not well defined, the procedures to follow are not nearly so evident. Perhaps the most important of these nebulous areas is that of the pilot's inherent decision-making capabilities.

4.0 The decision-making capabilities of the pilot.

At the risk of sounding metaphysical, we suggest that there are some tasks that are critical, in part, because they do not seem to be critical. We also suggest that this type of critical task occurs more often than we can ever know -- after an aircraft accident, we can never be sure whether the pilot may have failed to notice, ignored, or rejected some clue to the impending problem which, if acted upon correctly, might have allowed him to avoid the accident. Upon reflection, any pilot can recall instances in which something unusual or out-of-the-ordinary seemed to be happening with an instrument or, perhaps, with the aircraft's response to a control movement. Not being quite sure what was going on, he may have waited a bit and found that the problem seemed to go away. Whether he realized it or not, he was making a decision -- a decision to wait and see. The fact that he is around to reflect on his decision indicates that his decision was correct or, at least, that the problem was not really important. The haunting thought is that there are many pilots who are not around to second-guess an incorrect decision about a problem that really turned out to be important. It is because decisions are being made almost continuously, whether obvious or not, that we suggest that the decision-making characteristics of the pilot deserve greater attention than they have received.

4.1 Elements of a critical pilot decision.

A critical pilot decision can be treated as consisting of four stages, each of which should be carried out correctly if a correct decision is to be made:

(a) The pilot must first detect that a problem exists that requires a decision.

(b) Next, he must gather whatever data he can to identify the possible causes of the problem. He must also estimate the probability that each possible cause is, in fact, the actual cause.

(c) Then, he must evaluate the effects of each alternative response he can make. He must assign a value or cost to each response for each possible cause.

(d) Finally, he must choose the response that best satisfies his decision strategy, given his estimates of probable causes and his estimates of the costs and values of various outcomes.

Each stage of this process requires different abilities of the pilot and carries with it different problems.

4.2 Detection of a possible problem.

The process of detecting that a problem exists that requires a decision is itself a process of decision making. It is now well established that a sensory stimulus is not simply dichotomized as present or absent by means of a fixed threshold device in the peripheral sensory system. It is rather the case that the observer sets a decision criterion at some point along a continuum of sensory inputs more or less likely to represent signals in the presence of noise, or alternatively stated, that he adjusts a "response bias." The location of the criterion for the decision "signal present," or the amount of bias in favor of that response, is affected by the factors just described: the a priori probability of signal occurrence, and the values and costs of the various possible decision outcomes. Statistical-decision theory requires that all these factors be considered in an optimally-determined decision process.

The value of realizing that the detection process is a decision process is that statistical-decision theory enables one to separate sensory acuity from the non-sensory factors involved in detection. By analyzing the relationship between correct-detection responses and false-alarm responses, one can determine whether an observed change in performance resulted from a change in sensory acuity or from a change in the decision criterion or response bias. Evidence shows that a relatively strong signal will not be detected if the decision criterion is strict. In a technical report prepared under an earlier contract (NASw-676) for NASA's Office of Advanced Research and Technology, Green and Swets (Signal Detection Theory and Psychophysics, New York: Wiley, 1966) presented the decision-making theory of signal detection and reviewed the experimental results on visual and auditory signals. Under a previous contract with the Human Performance Branch of NASA-Ames, as described in BBN Report No. 1671, it was shown experimentally that this theory applies as well to vibratory signals.

Several other technical reports prepared under the last-mentioned contract (NAS2-2676) dealt with other aspects of the detection process. One, BBN Report No. 1440, presented extensive data on the observer's decision process when he makes the decision, alluded to earlier, to "wait and see." In this case, the observer accumulates additional information over time to increase the accuracy of his "signal/no-signal" decision, and must balance the value of increased accuracy against the cost of letting time go by. Our studies showed that with proper training observers can integrate the information in a series of observations; that they behave in an optimal manner in balancing accuracy against time; that they are more efficient when they can determine how long to observe than when the observation period is fixed; and that the lengths of observations preceding signal and no-signal decisions vary appropriately with changes in signal probability. Another study, described in BBN Report No. 1419, extended the theoretical concepts to treat temporal uncertainty about signal occurrence; it was shown that the observer's detection performance under temporal uncertainty can be predicted from his performance when under no temporal uncertainty.

In the limit, signal detection with uncertain times of signal occurrence becomes a process of vigilance. Basically, the pilot's detection of a possible problem is a vigilance task. He must continuously monitor his instruments and visual displays, as well as his vestibular and other sensory inputs, in search of a signal that might indicate something wrong. It has long been recognized that the proportion of signals detected falls off significantly in a vigilance task as time proceeds. It is now recognized that this drop in the detection, or "hit," probability is not simply a result of observer fatigue or inattention, but is rather a result of a change in his response criterion. His false-alarm proportion drops along with the hit proportion, in a manner to indicate that his sensitivity stays substantially the same. Apparently, as the observer gains experience in monitoring a particular signal, he learns that the events for which he is watching are rare. Therefore, a downward shift occurs in his *a priori* expectation of signal presence, and he adopts a stricter criterion for the decision "signal present." Swets and Kristofferson have reviewed the literature on vigilance, and have outlined additional research necessary, in a progress report submitted under the present contract that is soon to appear in the *Annual Review of Psychology* (Volume 21, 1970).

This phenomenon of criterion change may be of importance in the early detection of possible danger signals by a pilot. On the one hand, as a pilot gains experience, he is better able to judge what is an unusual instrument reading or an unusual aircraft response to his control actions under various conditions.

On the other hand, he learns that the vast majority of these unusual occurrences turn out to be of little consequence. Therefore, while the detectability of a certain event may increase, the pilot's response criterion may change in such a way as to decrease his hit rate. In order to ensure the earliest possible detection of an incipient problem, ways might be explored to lead the pilot to relax his decision criterion. Early-warning devices might be employed to make a possible problem more apparent to the pilot. Alternatively, attempts might be made to find ways to lower the apparent cost to the pilot of a false-alarm response. These attempts might involve the simulation of various failures during training activities and the encouragement of early detection by the pilot.

The pilot needs not only to sustain his general attentiveness through periods of vigilance, but also to time-share a selective attention among several sources of signals. In the same report mentioned above, Swets and Kristofferson have reviewed the theoretical and experimental literature on selective attention. Limitations on attention at any moment appear to be so severe that most of the results are described in terms of the so-called "single-channel" model. BBN Report No. 1675 to NASA-Ames describes our application of this model to weak vibratory signals presented to two fingers: the experiments showed that observers could not attend simultaneously to these two input channels.

4.3 Identification of possible causes.

Having detected an unusual occurrence, the pilot must estimate the probability of each possible cause of the problem. His ability to do this with accuracy will, of course, depend on his experience, training, and technical understanding of the system he is controlling. This point is well recognized, and is the reason why so much effort is expended in pilot training toward familiarizing the student with the signs of an impending stall, with the characteristics of the aircraft in various unusual attitudes, and with other emergency conditions that he may never experience.

It is clear that training of this type is quite valuable. Simulators can be used to confront the pilot with those situations that cannot be produced safely in actual aircraft. It is likewise clear that this training should not end completely when the pilot is licensed: a pilot suddenly confronted with a situation which he has not experienced in some months or years may not recall quickly enough the things he was taught.

4.4 Evaluation of the effects of alternative responses.

Having identified the possible causes of the problem, the pilot must consider the values and costs of each alternative response he can make. Again, the ability of the pilot to identify rapidly a set of responses appropriate to each possible cause will depend on his experience and training. In some cases, when the cause of the problem can be identified with virtual certainty, there may be only one appropriate response to be made. In other cases, an appropriate response to one possible cause may be grossly inappropriate to another. In these cases, it is imperative that the pilot consider the values and costs of all potential responses.

The assessment of costs (or values) can be a decidedly non-trivial process, since in many cases the pilot will be forced to compare costs (or values) that have no common metric. Consider, for example, the predicament of a pilot faced with a rapidly-falling fuel-level reading. Presume that he has good reason to believe that in fact he has plenty of fuel, and that it is the gauge that is in error. Nonetheless, the possibility exists that fuel is leaking away and that grave danger may result if he does not divert immediately to the nearest available airport. If he does divert the flight, he and his passengers are likely to experience a lengthy delay. In a case like this, the pilot must attempt to balance the cost of the expected delay against the possibility of catastrophe. The cost of a catastrophe is, in one sense, infinite to the people involved. However, it is clearly demonstrable that people do not treat the cost as infinite in many situations: they are willing to accept a small probability of death in order to avoid some other alternative that is almost certain to be distasteful. Many accidents have resulted when pilots have elected to try to stretch their fuel reserves or to continue a flight even after they have been warned of adverse weather conditions along their course.

Many of these accidents could be avoided if the pilots could be convinced of the propriety of making more conservative decisions. This problem can be attacked from two directions. First, pilots can be educated to the fact that the likelihood of disaster in certain situations is higher than they may have cared to admit to themselves. Second, attempts may be made to lower the cost of a conservative decision. For example, an airline might examine its policies to see if it is overpenalizing a pilot who terminated a flight without reaching his destination when this termination turns out not to have been necessary. The first approach is more likely to prove successful with lower types of airman certificates, who may through inexperience be mis-estimating probabilities. The second approach is most likely to succeed with experienced pilots whose danger estimates are accurate, but who are likely to take some risks if the cost of a conservative decision seems too high.

It has been suggested that the significantly higher accident rate experienced by medical doctors in non-business flying may be explained with considerations similar to those just mentioned. On the one hand, it is argued, doctors who have daily experience with death may have developed some feeling of immunity to disaster -- they may not be willing to believe that it could happen to them. On the other hand, their busy schedules may lead them to place a much higher cost on delays and postponements than other pilots might. They may, for example, realize that if they don't get a trip in this weekend, they may not have another chance for some time. Both effects together may lead them to accept risks that other pilots might not.

4.5 <u>Choice of the best response.</u>

Having estimated the costs of his various alternative responses, the pilot is still faced with choosing the response to make. Which one he chooses will depend upon his decision strategy. He may choose the response that has the lowest expected value of cost, given his estimate of the probabilities that various causes are true. Or he may choose the response that minimizes the maximum cost if it turns out not to be correct. He may employ some other strategy that has some features of both strategies just mentioned. There is no obvious reason why one particular strategy would be superior to all others. It would, clearly, be very interesting to determine in carefully-controlled simulator experiments the types of strategies that pilots actually employ.

Regardless of the strategy that the pilot employs, he will be forced to use it while under emotional and mental stress. It is well known that stress can significantly affect human decisions. In some cases stress may cause an individual to fixate on a single input channel or source of information. In other instances stress leads to an inability to come to a decision. Lieblich ("Effects of Stress on Risk Taking," Psychonomic Science, 10, 303-4, 1968) has described an experiment in which subjects were required to place bets while under the stress of electric shocks applied at random intervals. A risk-taking metric was chosen by which the subjects' betting strategies could be characterized. A low-risk strategy involved placing bets with a small positive expected value, but no chance of a large win. A high-risk strategy involved placing bets with a negative expected value, but with some chance of a very large win. It was found that the presence of stress led the subjects to assume a higher-risk strategy. This was true whether or not they were led to believe that they could avoid the shocks by altering their strategies. When they did believe that the shocks were somehow connected with their bets, however, they tended to vacillate far more in placing their bets.

Vacillation by a pilot in making a decision may greatly reduce the chances of his making the proper decision in time. When the time lost in gathering further data decreases the probability of recovery more than the information gained increases it, the pilot should no longer defer his decision. In some instances he must choose the response that is best according to available data, however inadequate he may feel those data to be. We suggest that simulator studies of pilot behavior might also prove useful in investigating his decision-making under stress. Where vacillation is found to be a problem, ways might be explored to force the pilot to an early decision, to a shorter reaction time.

Several of our technical reports under the previous and current contracts have dealt with aspects of reaction time. Two, BBN Reports Nos. 1729 and 1921, describe an extension to reaction time of the deferred-decision (or "wait-and-see") model developed in the context of the decision making theory of signal detection for sequences of discrete observation intervals. In our experiments, the subject had to decide whether two successively-presented stimuli were the same or different; that is to say, he had to detect a change, which is the type of decision a pilot makes continually. The results are consistent with a model assuming that the subject uses a "counter" for cumulating "difference" information and a "clock" for keeping time; that he sets both a count criterion and a time criterion in accordance with stimulus probabilities and decision-outcome values and costs; that his decision rule is to decide "different" if the count criterion is exceeded before the time criterion, otherwise to decide "same." Predictions were made for the relationships among reaction times associated with correct and incorrect "same" and "different" decisions in a variety of experimental conditions. The fact that an individual's subjective probabilities and utilities affect his reaction time suggests that analyses should be made of pilots' estimates of these quantities in various situations, and that training will be desirable when these estimates are inaccurate.

Three reports describe our work on the efficacy of associating a warning signal with a signal that requires a response (or danger signal). BBN Report No. 1888 described the effects of a preceding or following auditory stimulus on reaction times to a visual stimulus. Both the occurrence of the tone and the possibility of its occurrence were found to affect the reaction time to the light. The effect of the tone was facilitative, the degree of facilitation increasing up to a point with the duration of the tone-light interval. Some facilitation apparently occurred even when the tone followed the light, providing the interval between them was sufficiently brief. Report No. 1679 described various effects of a warning signal on the reaction time to a signal to respond. Reaction time was inversely related to the interval between warning signal and signal to respond; when the interval was constant its duration had no effect on reaction time; reaction times were shorter with a constant interval of any duration than when the warning signal was omitted altogether. BBN Report No. 1690 relates further experiments on the effectiveness of warning signals. In these experiments the interval between the warning signal and the signal to respond was variable, and the warning signal was followed by a danger signal with probability less than 1.0. Observers were found to differ considerably in the use made of the probabilistic warning information, and a model was developed to describe the different response strategies they used.

A recent experiment, described in BBN Report No. 1826, examined reaction time to flashing visual indicators. A determination was made of the optimal flash rate and duty cycle where the observer's task is to decide quickly whether the light is flashing or steadily on. The signal was initiated at a random point in its cycle to simulate conditions of low attention, as might be caused by a heavy workload. As in our earlier experiments, observers were found to adopt a time criterion, or a predetermined waiting period -- in this case a criterion appropriate to the expected flash rate and duty cycle.